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Dyer et al.

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(54) **PROVIDING EQUIPMENT IN LATERAL BRANCHES OF A WELL**

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CPC **E03B 3/14** (2013.01); **E21B 41/0035** (2013.01); **E21B 47/12** (2013.01)

(58) **Field of Classification Search**

USPC 166/254.2, 66, 50, 250.01, 266; 175/48, 175/50

See application file for complete search history.

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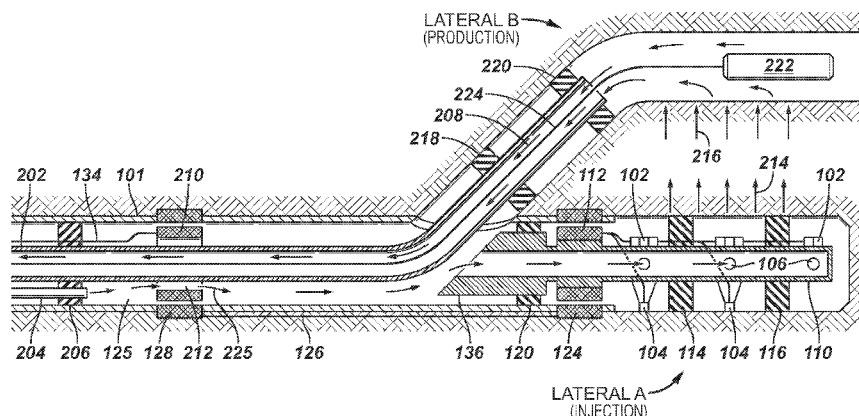
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(57)

ABSTRACT

First equipment is provided in a first lateral branch of a well, and second equipment in a second lateral branch of the well. Cross-lateral logging is performed using the first and second equipment in the corresponding first and second lateral branches.

22 Claims, 10 Drawing Sheets



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FIG. 1A

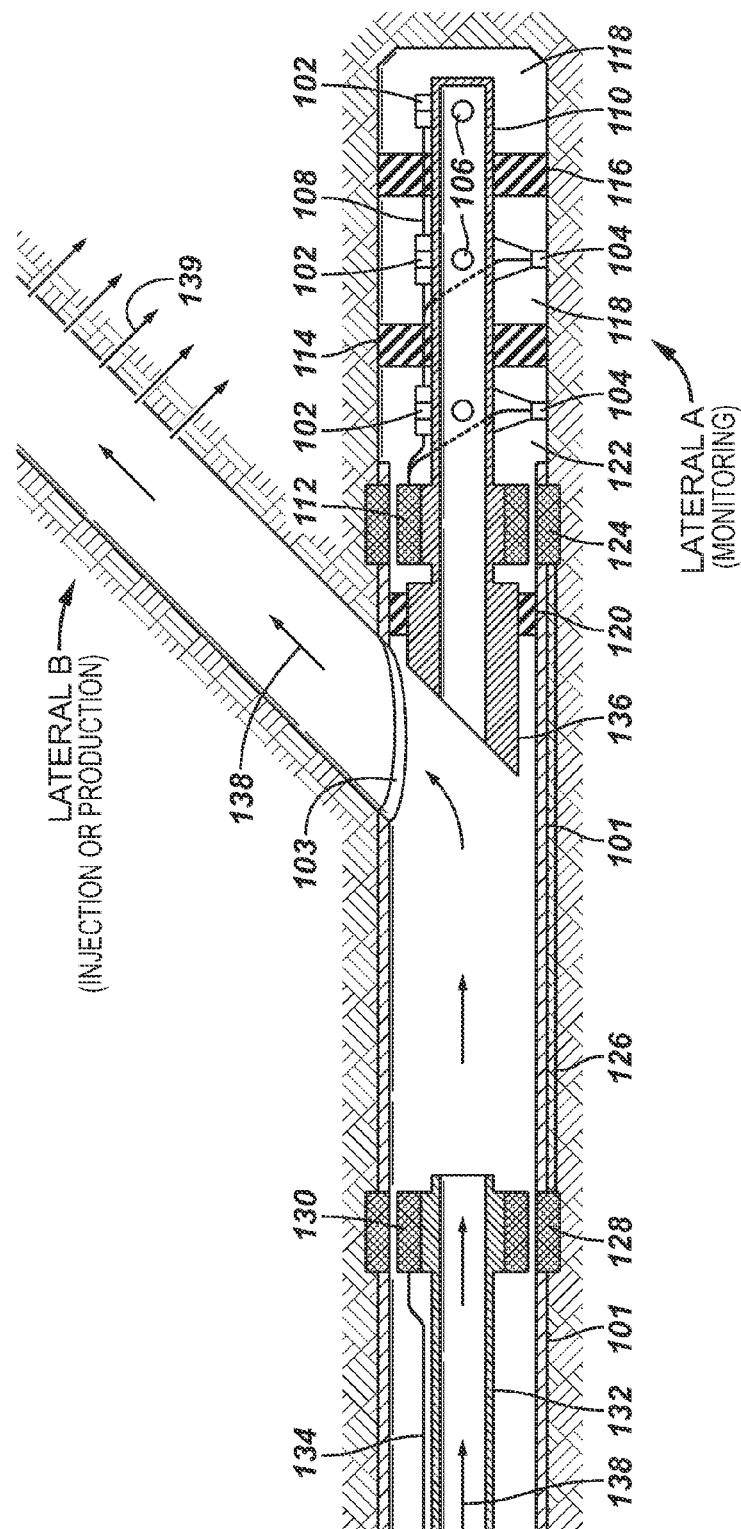


FIG. 1B

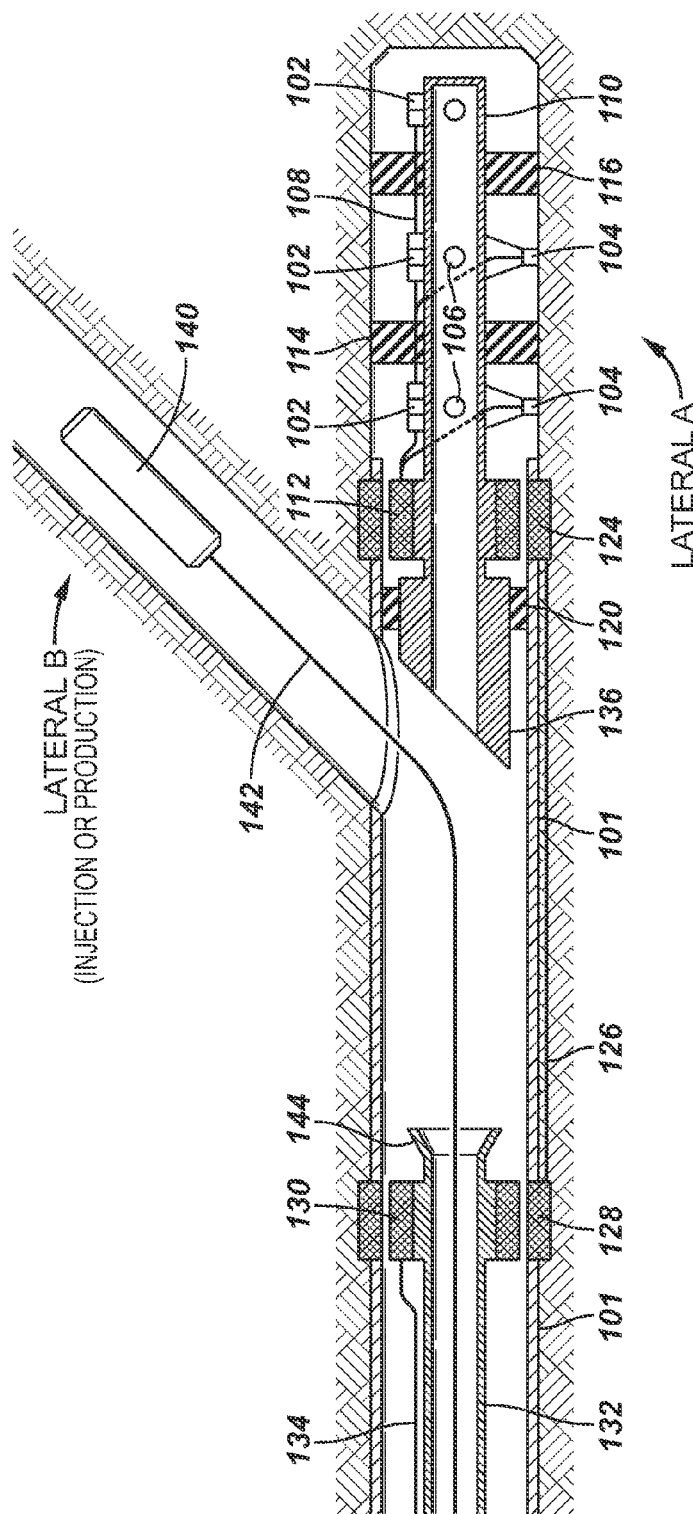


FIG. 1C

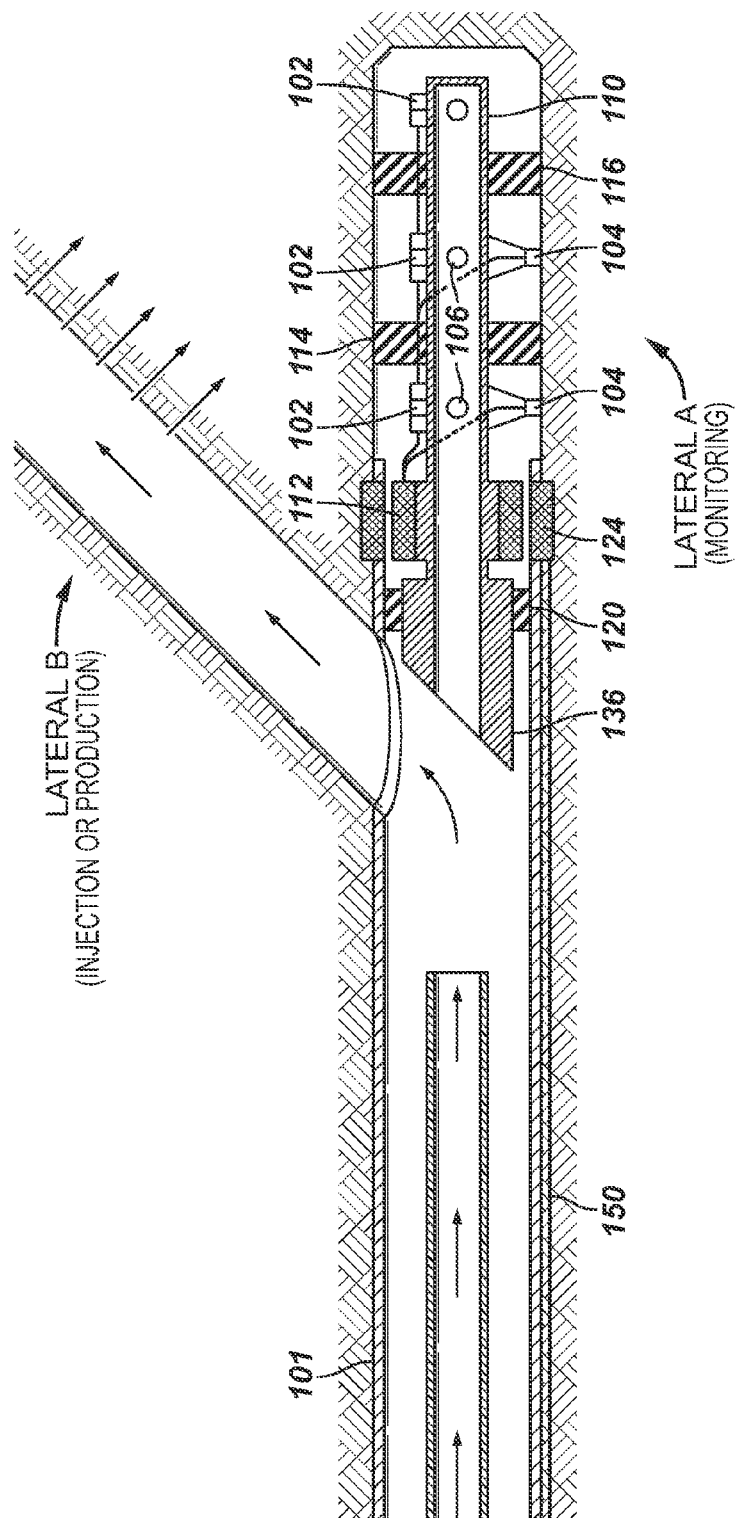


FIG. 2A

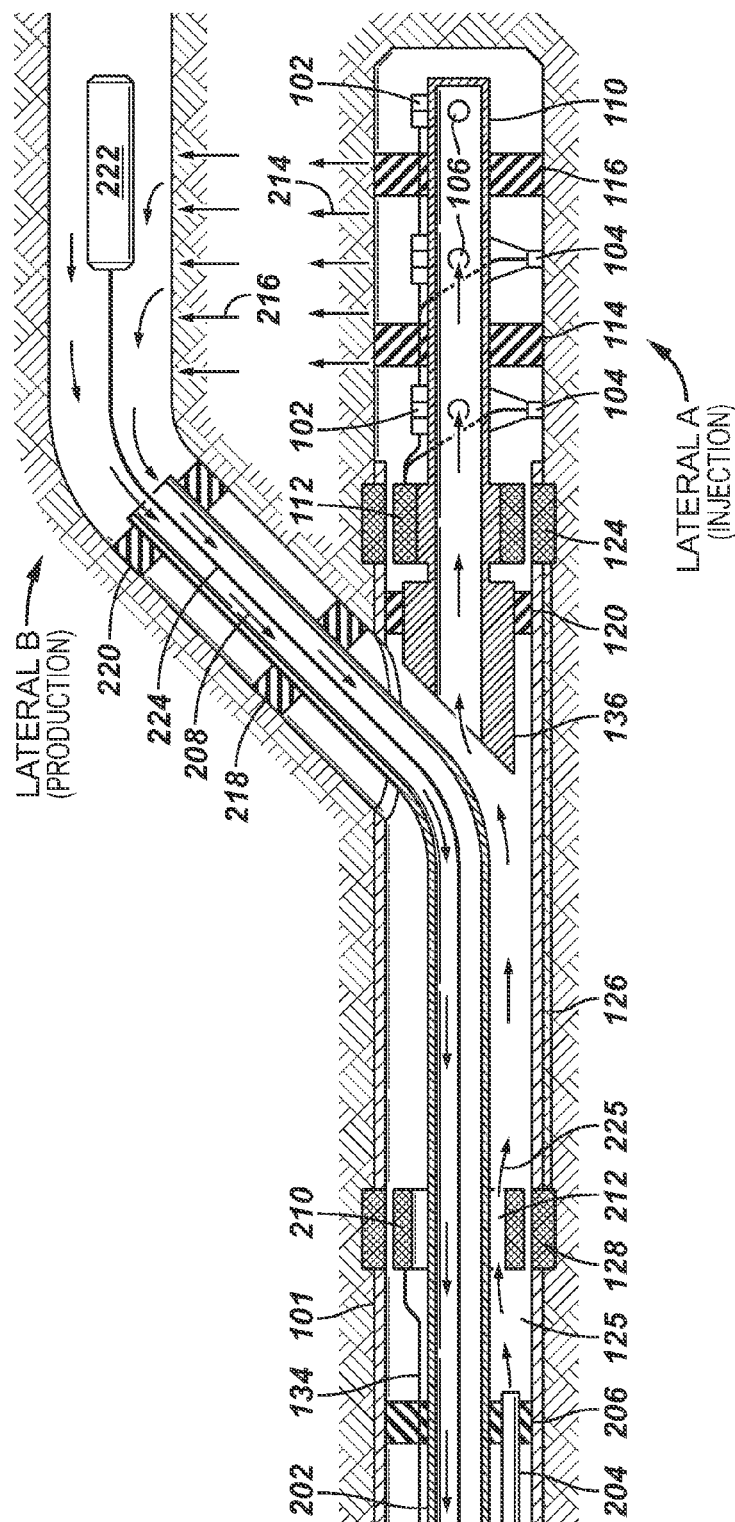


FIG. 2B

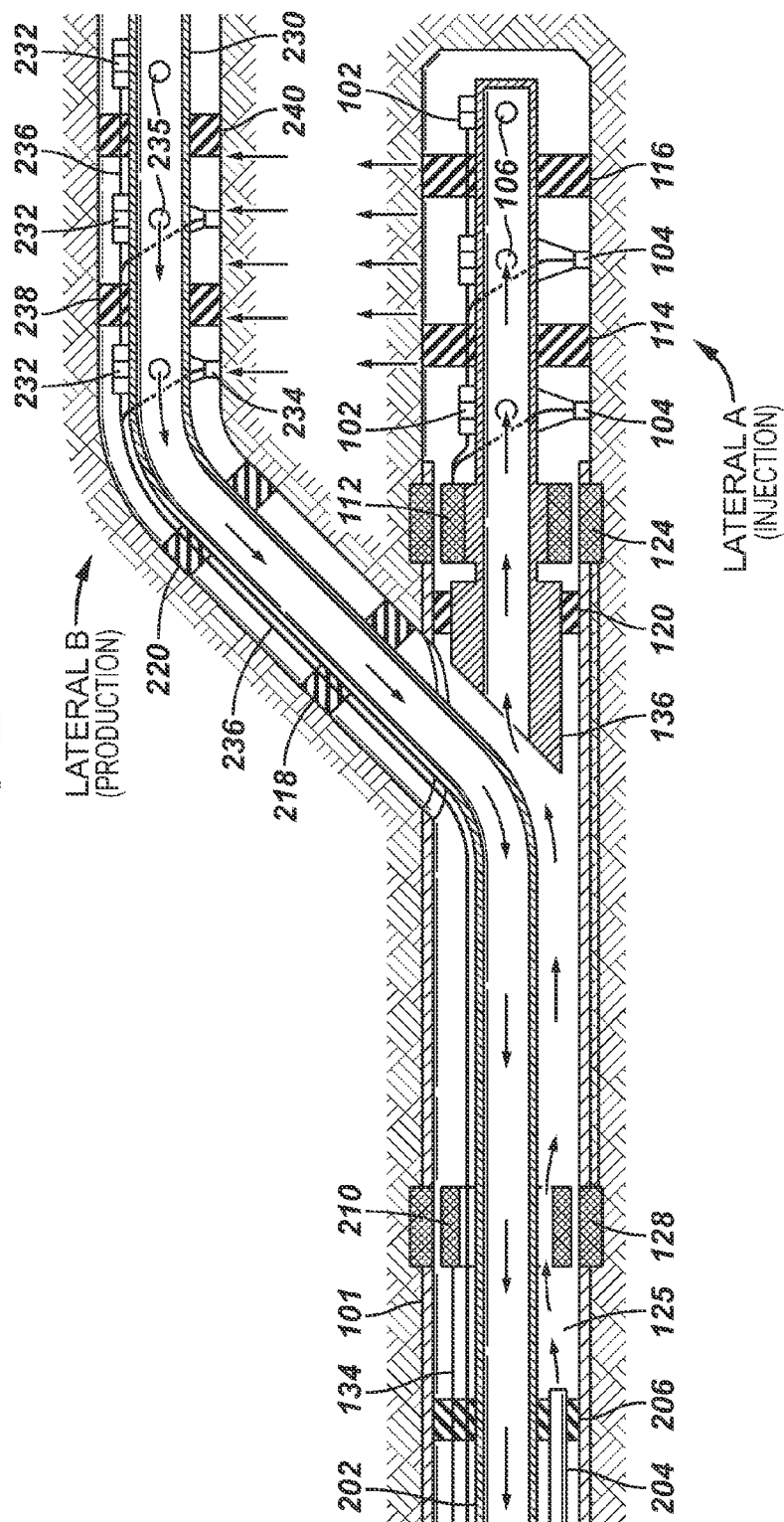
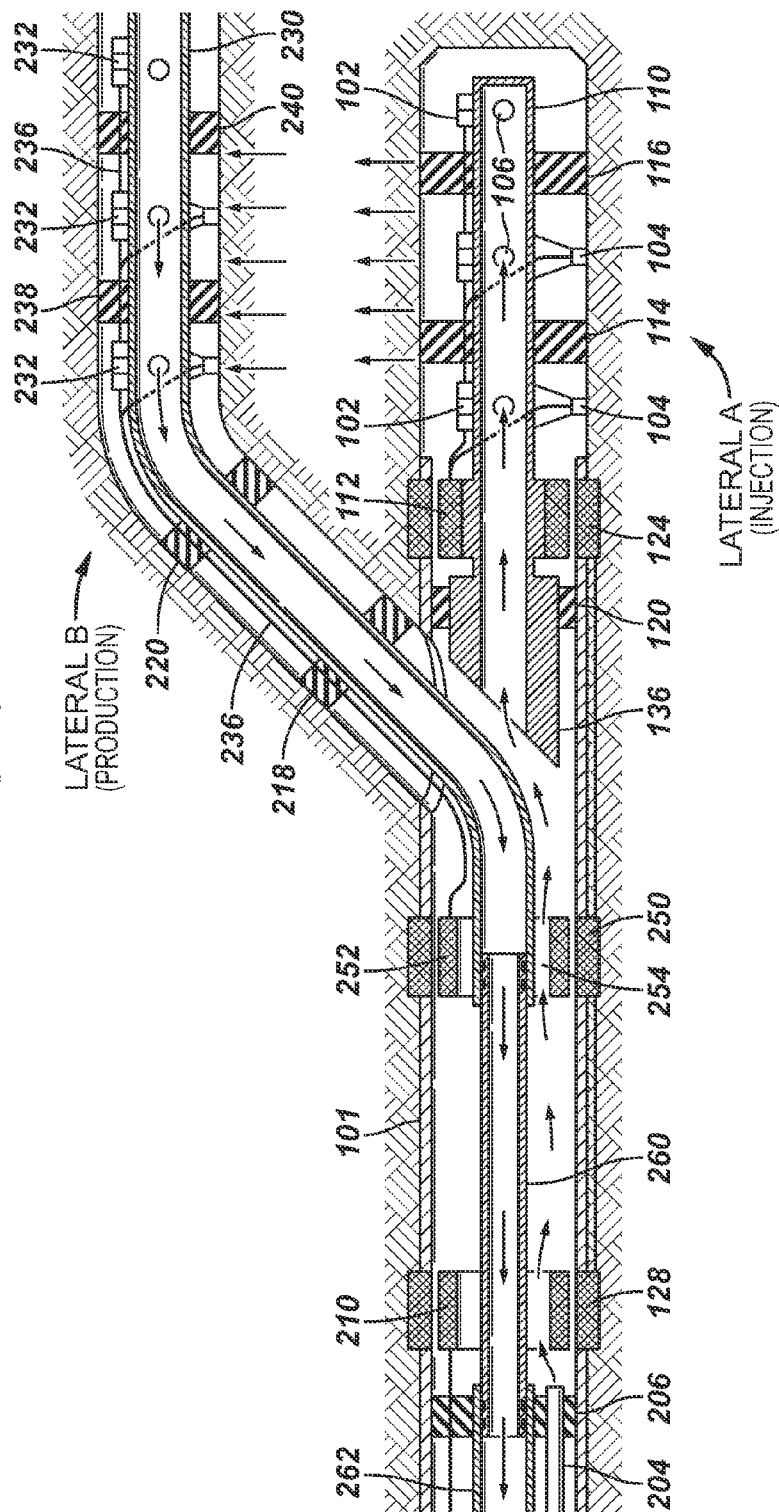


FIG. 2C



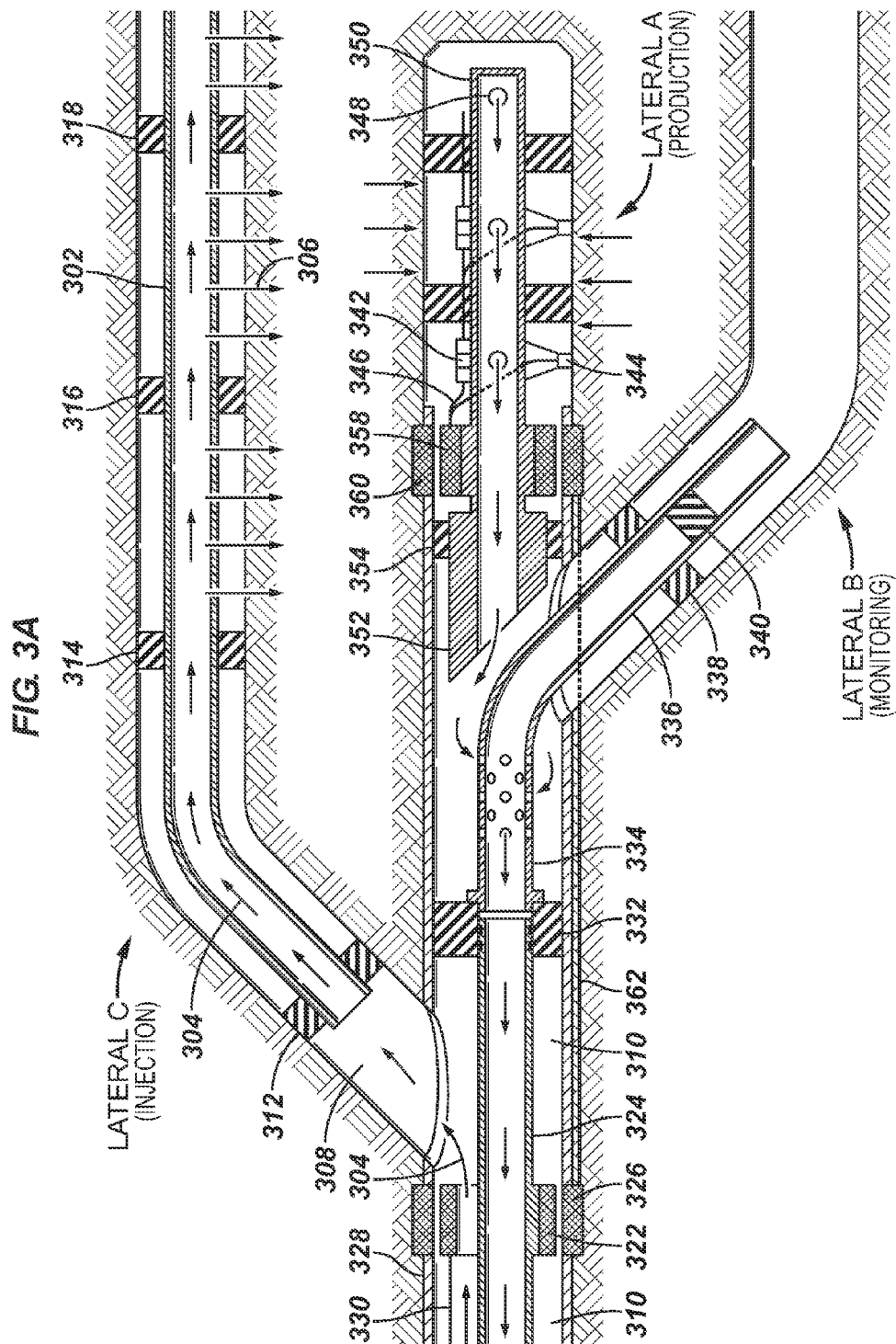
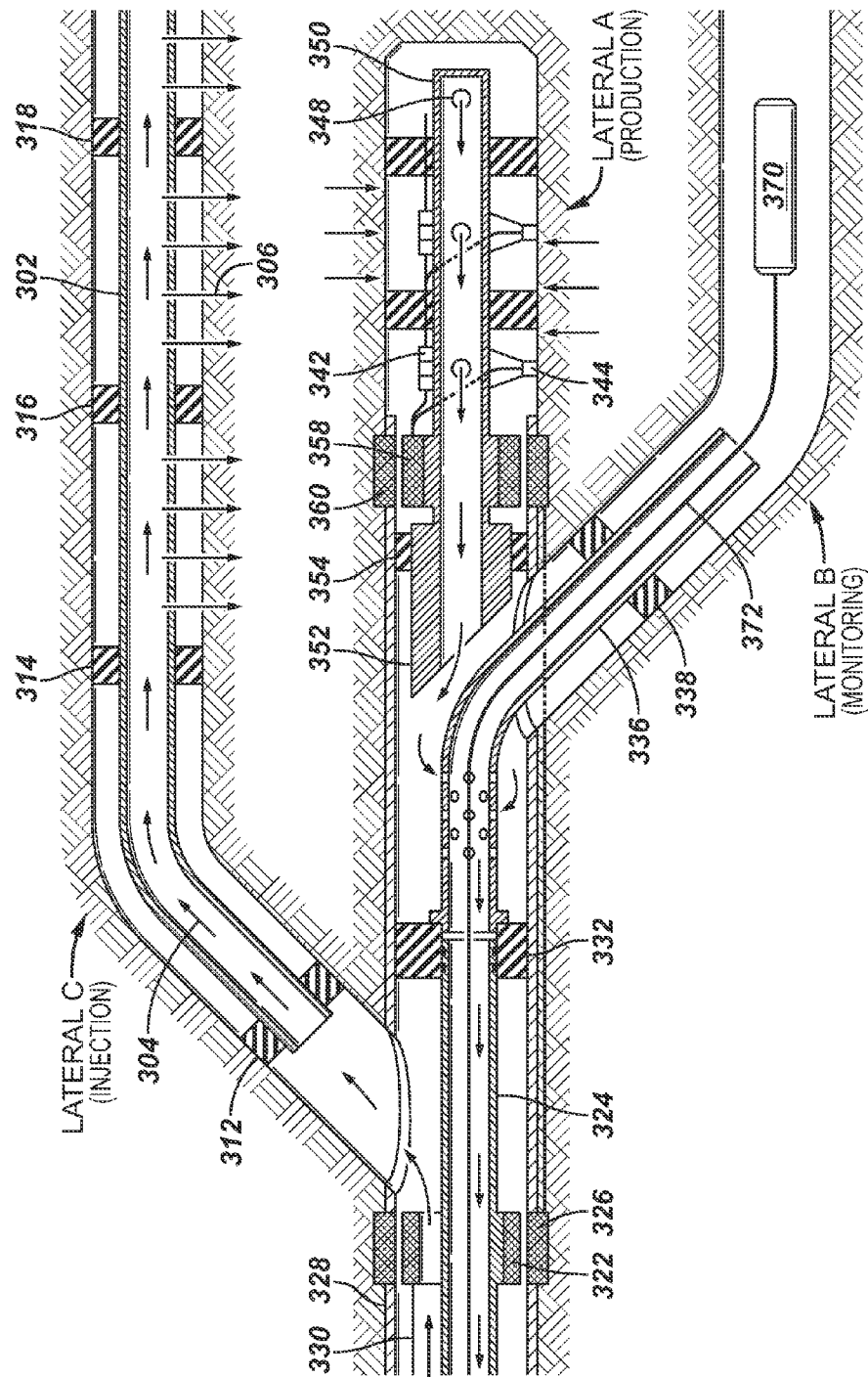
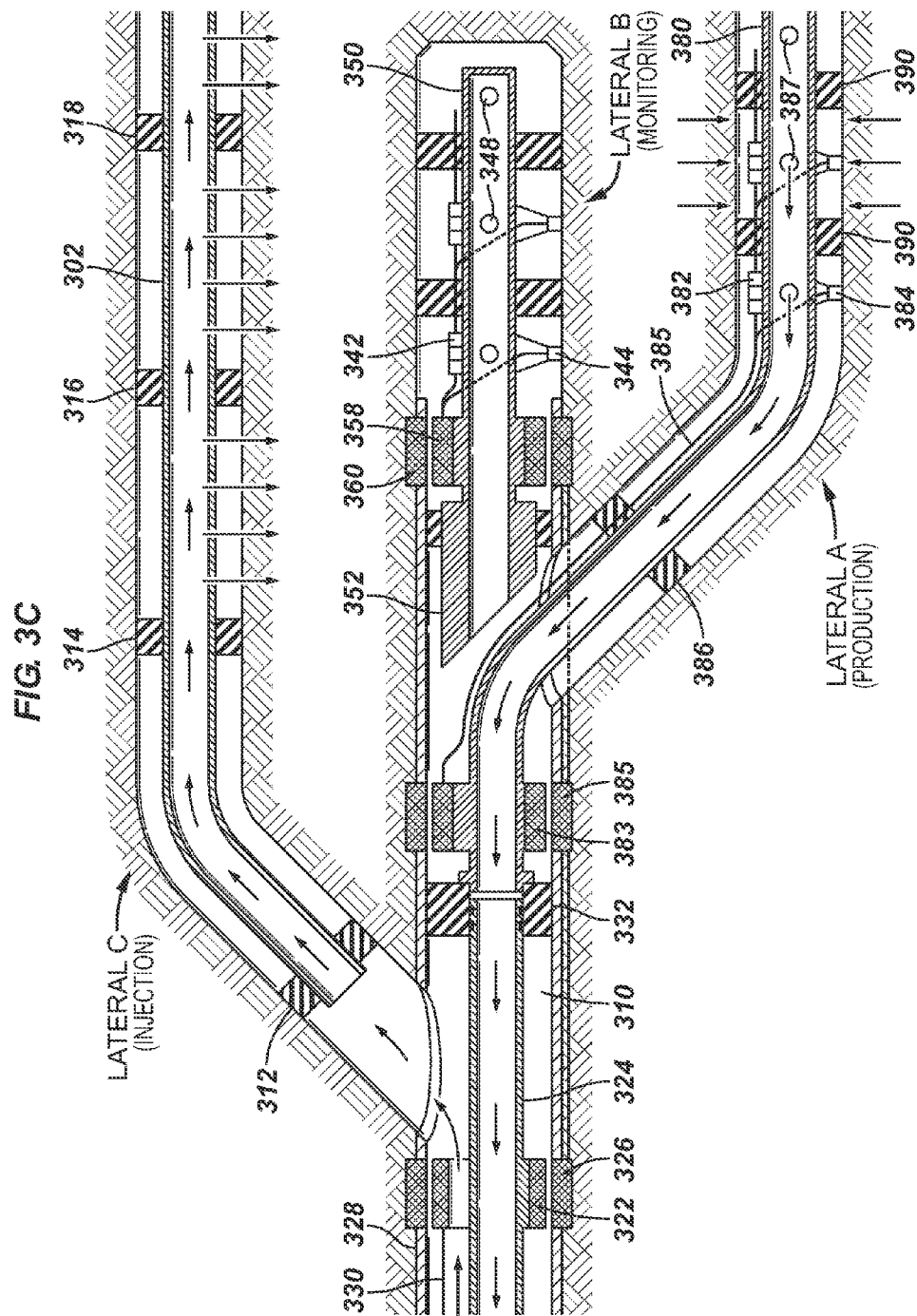
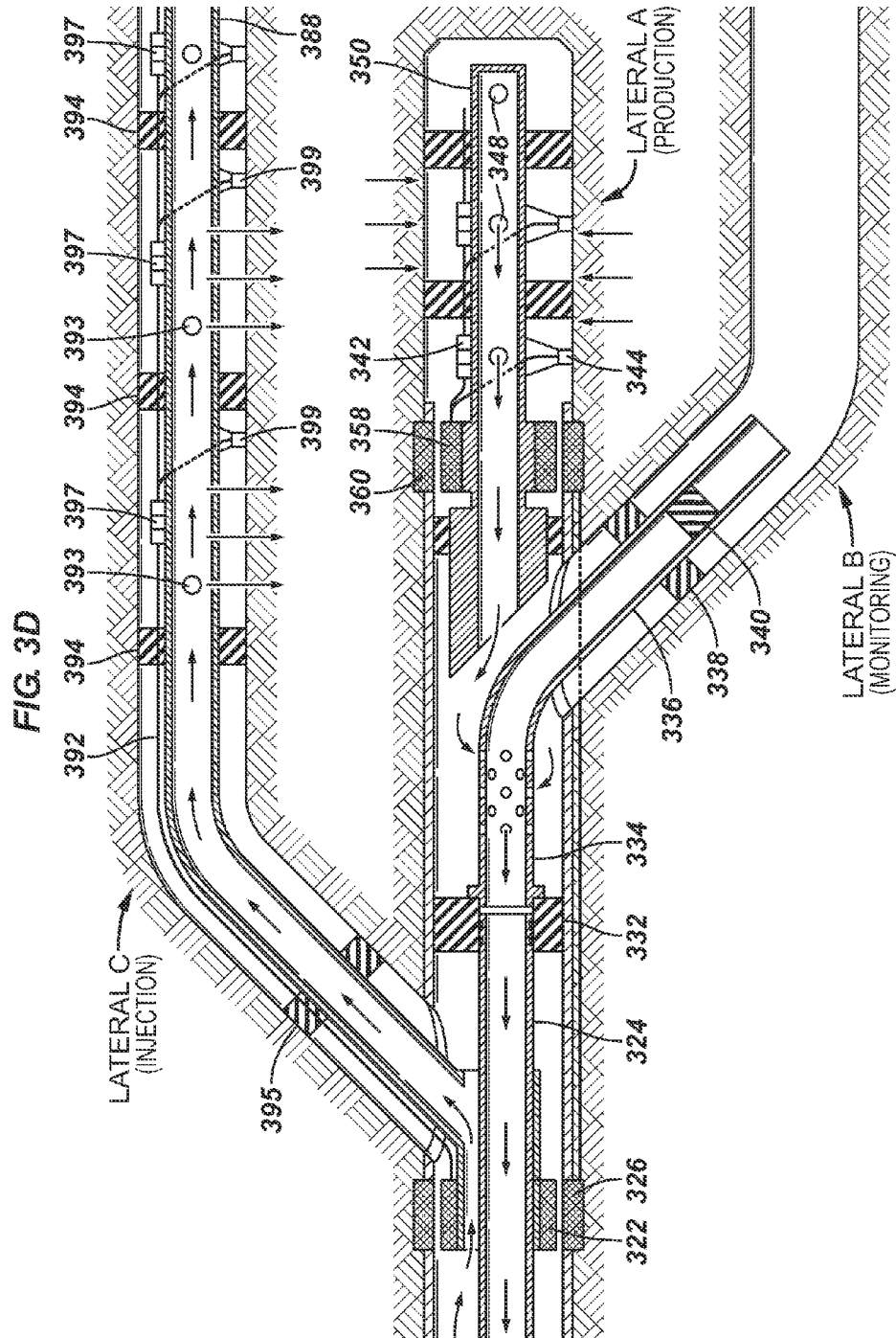


FIG. 3B







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PROVIDING EQUIPMENT IN LATERAL BRANCHES OF A WELL

CROSS-REFERENCE TO RELATED APPLICATION

This application claims the benefit under 35 U.S.C. §119 (e) of U.S. Provisional Application Ser. No. 61/543,100, entitled "Providing Equipment in Lateral Branches of a Well," filed Oct. 4, 2011, which is hereby incorporated by reference.

BACKGROUND

A well can be drilled into a subterranean structure for the purpose of recovering fluids from a reservoir in the subterranean structure. Examples of fluids include hydrocarbons, fresh water, or other fluids. Alternatively, a well can be used for injecting fluids into the subterranean structure.

In some cases, a well can have multiple lateral branches. Equipment can be provided in these lateral branches to perform various well operations.

SUMMARY

In general, according to some implementations, first equipment is provided in a first lateral branch of a well, and second equipment in a second lateral branch of the well. Cross-lateral logging is performed using the first and second equipment in the corresponding first and second lateral branches.

Other features will become apparent from the following description, from the drawings, and from the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

Some embodiments are described with respect to the following figures:

FIGS. 1A-1C illustrate example well equipment of a first arrangement type in a multilateral well having lateral branches, according to some implementations;

FIGS. 2A-2C illustrate example well equipment of a second arrangement type in a multilateral well having lateral branches, according to further implementations; and

FIGS. 3A-3D illustrate example well equipment of a third arrangement type in a multilateral well having lateral branches, according to additional implementations.

DETAILED DESCRIPTION

As used here, the terms "above" and "below"; "up" and "down"; "upper" and "lower"; "upwardly" and "downwardly"; and other like terms indicating relative positions above or below a given point or element are used in this description to more clearly describe some embodiments. However, when applied to equipment and methods for use in wells that are deviated or horizontal, such terms may refer to a left to right, right to left, or diagonal relationship as appropriate.

Completion equipment can be installed in a well to allow for various operations to be performed, including fluid production and/or injection operations. As examples, the completion equipment can include a casing or liner, fluid conduits (e.g. tubings, pipes, etc.), flow control devices, sand control elements, pumps, sealing elements (e.g. packers), sensors, and so forth.

In a well that has multiple lateral branches (or multiple "laterals"), equipment can be provided in the respective lat-

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eral branches to perform various operations, including fluid injection, fluid production, and/or monitoring operations. A well having multiple lateral branches can be referred to as a "multilateral well." A "monitoring operation" can refer to any operation that monitors either a condition in a well or a condition of the surrounding subterranean structure. Examples of monitoring operations include any or some combination of the following: monitoring a front of the fluids as the fluids are injected into an injection lateral branch; monitoring a front of fluids produced into a production lateral branch; monitoring a property of a subterranean structure surrounding a lateral branch or between lateral branches, where the property can include resistivity or any other property; monitoring fluid flow inside a lateral branch; and so forth.

Fluids that can be injected into a well lateral branch can include surfactants, solvents, polymers, engineered water, gas (such as carbon dioxide or hydrocarbon gas), and so forth. In some cases, the cost of the injected fluids can be relatively high. The ability to monitor injection of fluids can result in more cost-effective injection operations. Monitoring injection of fluids can help identify the location of fluid flow paths during stimulation operations, such as acid wormholing, matrix treatments, acid or proppant based fracture treatments, conformance treatments (e.g. injection of polymers for water shutoff, injection of foams and emulsions, etc.), injection of solids or solid particulates (e.g. proppant, sand, polymeric materials, encapsulated solids, nano-particles, magnetic powders, etc.), and so forth.

In accordance with some implementations, equipment can be provided in respective lateral branches of a multilateral well, where such equipment in the lateral branches can be used to perform cross-lateral logging, injection of fluids, production of fluids, and/or other operations. Cross-lateral logging can involve performing a monitoring operation using monitoring equipment in a first lateral branch in response to an operation (e.g. injection, production, etc.) in a second lateral branch. In some implementations, cross-lateral logging can use a signal emitter in a first lateral branch to produce a signal that is emitted into a subterranean structure adjacent the first lateral branch. Also, a signal sensor (or signal receiver) in a second lateral branch is able to receive the emitted signal, as affected by the subterranean structure. The data received by the signal sensor can be processed to identify a property of the subterranean structure. The emitted signal can be an electromagnetic signal. In other examples, the emitted signal can be an electrical current, an electrical voltage, an oscillating current, an acoustic signal, seismic signal, pressure wave, an irradiated nuclear signal such as a gamma ray signal, heat, a pressure pulse, a chemical emission, and so forth. Although reference is made to a signal emitter and a signal sensor, note that in other examples a lateral branch can include multiple signal emitters (e.g. an array of signal emitters) and/or multiple signal sensors (e.g. an array of signal sensors). A lateral branch can also include a signal transceiver (or multiple signal transceivers), where a signal transceiver includes a component to emit (transmit) a signal and a component to receive a signal.

There can be various arrangements of equipment in a multilateral well. In some implementations, the multilateral well can include an injection lateral branch (into which fluids are injected) or production lateral branch (through which fluids can be produced) and a monitoring lateral branch (that includes monitoring equipment to perform a monitoring operation). In other implementations, the multilateral well can include an injection lateral branch and a production lateral branch, where the production lateral branch is used to

produce fluids (while the injection of fluids into the injection lateral branch is occurring). In further implementations, the multilateral well can include an injection lateral branch, a production lateral branch, and a monitoring lateral branch. There can be other example configurations as well.

Arrangement Type #1

FIGS. 1A-1C depict example well equipment according to arrangement type #1. Although various example configurations of well equipment are shown in FIGS. 1A-1C, it is noted that other example configurations according to arrangement type #1 can be used. Generally, arrangement type #1 includes a monitoring lateral branch (lateral A) and an injection or production lateral branch (lateral B).

Note that various components in the example well equipment can operate using any one or more of the following types of communications: electrical communications, optical communications, hydraulic communications, and so forth.

Electrical communications can be accomplished using an electrical cable. Optical communications can be used using an optical fiber (or optical fibers) through which optical signals can be propagated. Hydraulic communications can be performed using a hydraulic control line through which hydraulic pressure can be applied for controlling a component.

FIG. 1A shows a multilateral well that has a monitoring lateral branch (lateral A) and an injection or production lateral branch (lateral B). Each of laterals A and B can be an open hole well section, or a lined section of a well. As depicted, the well equipment deployed in lateral A (the monitoring lateral branch) includes sensors **102**, **104** and flow control devices **106**. In further examples, additional and/or other electrical or other activatable devices can be included in the well equipment in lateral A. Additionally, tools can be run into lateral A (such as through a tubing **110** in lateral A) to perform intervention operations, such as logging, mechanical or hydraulic manipulation, pumping, and so forth.

The sensors **102** can be used for measuring various conditions in a wellbore, including one or more of the following characteristics: pressure, temperature, chemical content, salinity, fluid resistivity, gas content, fluid flow rate, fluid capacitance, particulate concentration, and so forth. The sensors **102** are interconnected by an electrical cable **108** to an inductive coupler portion **112**. In examples according to FIG. 1A, the sensors **102** and cable **108** are arranged along an outer surface of the tubing **110**, which defines an inner conduit through which fluid can flow (and through which an intervention tool can be run).

FIG. 1A also shows isolation packers **114** and **116** (to provide hydraulic isolation) that are engaged between the outer surface of the tubing **110** and the wall of lateral A, to define sealed annular zones **118**. FIG. 1A also shows another sealing element **120** located uphole of the packer **114**—the sealing element **120** and packer **114** define another sealed annular zone **122**. The sealing element **120** is provided on a whipstock **136**. The whipstock **136** is a device that allows for deflection of tools into a lateral branch, such as lateral B in FIG. 1A. The tubing **110** is connected below the whipstock **136**.

Effectively, the isolation packers **114** and **116** and sealing element **120** provide a segmented completion in lateral A, which includes multiple segments for multiple respective zones.

The sensors **104** can be formation contact sensors, which are sensors that are provided in physical contact with a formation wall. For example, the contact sensors **104** can be mounted on pads or some other mechanism to provide allow physical contact between the contact sensors **104** and the wall

of the lateral branch. Examples of formation contact sensors include any one or more of the following: acoustic sensor, geophone, hydrophone, micro-resistivity sensor, electromagnetic sensor, pressure sensor, strain sensor, gamma ray detector, electric dipole measurement sensor, and so forth. In further examples, one or more of the sensors **104** can further include a transmitting element, or in different examples, one or more of the sensors **104** can be replaced with just a signal emitter. Examples of signal emitters include an electromagnetic emitter, a seismic source, an acoustic emitter, and so forth.

The formation contact sensors **104** can be used to detect signals from the adjacent formation (the formation adjacent or surrounding lateral A). An array of the contact sensors **104** (or an arrangement of discrete contact sensors **104**) can be used to develop a tomographic image of the medium in the adjacent formation. The formation contact sensors **104** can also be used to detect signals emitted from another lateral, such as lateral B. In this way, a tomographic image of the formation between lateral branches can be developed.

The formation contact sensors **104** can also be connected to the cable **108**. Although not shown, the flow control devices **106** can also be connected to the cable **108**. The cable **108** can be passed through feed-through paths in the packers **114** and **116**.

The inductive coupler portion **112** is positioned adjacent another inductive coupler portion **124**. The inductive coupler portion **124** is mounted to a liner **101**, which lines a portion of the well depicted in FIG. 1A. A liner is a lining structure used to line a wall of a well. The term “liner” can refer to a casing (which extends to the earth surface), or to a downhole liner that does not extend to the earth surface.

The proximal positioning of the inductive coupler portions **112** and **124** allow the inductive coupler portions to inductively communicate with each other. In some examples, the inductive coupler portion **124** is a female inductive coupler portion that defines an inner bore in which the inductive coupler portion **112** (e.g. a male inductive coupler portion) can be placed to align the inductive coupler portions **112** and **124**. The inductive coupler portions **112** and **124** together form an inductive coupler.

An inductive coupler performs communication using induction. Induction involves transfer of a time-changing electromagnetic signal or power that does not rely upon a closed electrical circuit, but instead performs the transfer wirelessly. For example, if a time-changing current is passed through a coil, then a consequence of the time variation is that an electromagnetic field will be generated in the medium surrounding the coil. If a second coil is placed into that electromagnetic field, then a voltage will be generated on that second coil, which is referred to as the induced voltage. The efficiency of this inductive coupling generally increases as the coils of the inductive coupler are placed closer together.

As further shown in FIG. 1A, the female inductive coupler portion **124** on the liner **101** is connected to an electrical cable **126**, which extends above the female inductive coupler portion **124** outside the liner **101** to another female inductive coupler portion **128** mounted on the liner **101**. The female inductive coupler portion **128** can be inductively coupled to an inductive coupler portion **130**, which can be a male inductive coupler portion provided at a lower portion of a completion tubing **132**. The male inductive coupler portion **130** on the completion tubing **132** can be aligned (positioned adjacent to) the liner female inductive coupler portion **128** when the completion tubing **132** is lowered into the well and placed in its target position.

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The completion tubing **132** has an inner conduit used to perform fluid injection or production. Tools can also be conveyed through the inner conduit of the completion tubing **132**. The completion tubing inductive coupler portion **130** is in turn connected by an electrical cable **134**, which runs generally along an outer surface of the completion tubing **132**. The cable **134** can extend to earth surface equipment, in some examples. In other examples, the cable **134** can extend to another component (such as a downhole controller) that is located in the well but is further uphole than the completion tubing inductive coupler portion **130**.

The cables and inductive coupler portions are used for transmission of power and for data telemetry. Power can be delivered from an uphole location (e.g. earth surface equipment or a downhole controller) through the various cables and inductive couplers depicted in FIG. 1A to the sensors and flow control devices in lateral A. Commands to activate (open or close) the flow control devices **106** can also be delivered from an uphole location to the flow control devices **106** through the various cables and inductive couplers. Data acquired by the sensors **102** and **104** can be communicated over the cables and inductive couplers to an uphole location.

In the foregoing discussion, reference has been made to inductive coupler portions and electrical cables to interconnect various components. In other examples, in addition to inductive coupler portions, or in place of inductive coupler portions, other types of coupler portions can be provided, including optical coupler portions and hydraulic coupler portions. Optical coupler portions are provided to allow for optical communications between components. For example, optical coupler portions can include optical lenses and other optical elements to allow for communication of optical signals between the optical coupler portions once they are brought into alignment with respect to each other. If optical coupler portions are provided, then optical cables (including one or more optical fibers) can be provided in place or in addition to the electrical cables depicted in FIG. 1A.

In other examples, hydraulic coupler portions can be provided, which can include hydraulic ports and hydraulic fluid passageways that are sealingly engaged to each other once the hydraulic coupler portions are brought into alignment. In such examples, hydraulic control lines can be used in place of or in addition to the electrical cables and/or optical cables.

If hydraulic communication is enabled, then actuation of hydro-mechanical devices can be performed using hydraulic pressure created by a pressure source (such as at the earth surface). Also, distribution of injected fluids—hydraulic fluids or chemicals—is possible, such as to inject tracers, chemical agents for enhanced fluid recovery, nano-particles, and so forth. The injection rate and location where the fluid is displaced can be controlled from surface or selectively placed using a surface controlled control valve connected to the injection line inside each segment of the well.

In some examples, a hydraulic coupler can include a female hydraulic coupler portion mounted to the liner, and a male hydraulic coupler portion aligned inside the hydraulic coupler portion. The devices in a lateral branch can then be controlled by hydraulic power and signals.

In the ensuing discussion, reference is made to inductive coupler portions and electrical cables. Note, however, that techniques or mechanisms according to some implementations can also be used in arrangements that employ optical coupler portions or hydraulic coupler portions in place of or in addition to inductive coupler portions.

In operation, according to some examples, injection fluids (e.g. liquids, solids, chemicals, polymers, cement, nano-particles, gas, acids, steam, etc.) can be flowed through the inner

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conduit of the completion tubing **132** (indicated by arrows **138**) into lateral B. A liner window **103** (an opening in the liner **101**) is formed (such as by milling) to allow for communication between lateral B and the main wellbore. The injected fluids are injected from lateral B into the adjacent formation (indicated by arrows **139**).

The sensors **102** and **104** in lateral A can monitor the front of fluids in the formation due to injection of fluids from lateral B. In some examples, these sensors can also be combined with transceivers and/or a logging tool in the injection lateral branch (lateral B) to provide a cross-lateral tomographic image. Measurement data collected by the sensors **102** and **104** can be communicated over the cable **108** to the first inductive coupler formed of portions **112** and **124**. The measured data is communicated by this inductive coupler over the cable **126** to the second inductive coupler formed of inductive coupler portions **130** and **128**. In turn, this second inductive coupler communicates the measured data over the cable **134** to an uphole location (e.g. earth surface equipment or a downhole controller).

The flow control devices **106** can be selectively actuated between open and closed positions, in response to commands received over the cables and inductive couplers of FIG. 1A. Although not explicitly depicted in FIG. 1A, the flow control devices **106** can be connected to the cable **108** to allow for commands sent from an uphole location (e.g. earth surface equipment or downhole controller) to be communicated to the flow control devices **106** to control actuation of the flow control devices. In some examples, in the context where injection fluid is injected into lateral B, the flow control devices **106** can be selectively opened to allow for production of fluids, pushed by the injected fluids, into the inner conduit of the tubing **110** in lateral A. This action of allowing production of fluids into the inner conduit of tubing **110** can enhance the displacement of the fluids from one lateral branch to another lateral branch, or can be used to clean up near-wellbore fluids that can be damaging to the displacement process.

The flow control devices **106** can be used to enhance the contrast of the fluid front in the formation between the laterals (A and B), or can be used to introduce specific chemicals or treatments into the formation surrounding lateral B for specific purposes.

Instead of the active flow control devices **106** depicted in FIG. 1A (in which the flow control devices **106** can be actively controlled), passive flow control devices can be used instead, where a passive flow control device can include an orifice choke, nozzle, or channel, as examples. Fluid flow through a passive flow control device is based on differential pressure across the orifice choke, nozzle, or channel (in a passive flow control device, there is no actuatable member that is settable between an open position and closed position).

In the ensuing discussion, although reference is made to active flow control devices, it is noted that passive flow control devices can be used instead in some examples.

In another example application, instead of injecting fluids into lateral B, fluid can be injected into lateral A, with the flow control devices **106** selectively opened to allow the injected fluids to pass into respective annular regions **118** and **122** to flow into the adjacent formation. Injection of fluids from lateral A into the adjacent formation causes fluid production into lateral B, where fluid can be flowed from lateral B to the completion tubing **132** (in a direction opposite the direction of the arrows **138**). In such example, the sensors **102** and **104** can be used to monitor the front of fluids produced into a production lateral (lateral B).

In this way, the following example applications can be provided by the arrangement of FIG. 1A: detection and con-

trol of chemical injection front; detection of wormholing penetration from a matrix acidization treatment; monitoring of fracture penetration; conformance treatment penetration into fractures; positioning of aggregated nano-particles or solid materials within the formation between laterals; and so forth.

FIG. 1B illustrates an example arrangement that is similar to FIG. 1A, except with a few modifications. Components of FIG. 1B that are identical to components of FIG. 1A share the same reference numerals. In FIG. 1B, a logging tool **140** that is carried on a carrier line **142** (e.g. wireline, slickline, coiled tubing, etc.) or that is carried by a downhole tractor is run down through the inner conduit of the completion tubing **132** and is directed by the whipstock **136** into lateral B. According to FIG. 1B, the lower end of the completion tubing can be provided with an entry guide **144**, to allow for easier retrieval of logging tool **140** back into the completion tubing **132**.

The logging tool **140** can include signal emitters, sensors, or transceivers to transmit or receive signals, including electrical signals, electromagnetic signals, seismic signals, acoustic signals, nuclear signals, and so forth.

In operation, according to some examples, signal emitters in the logging tool **140** can be used to emit signals that are transmitted into the formation between lateral A and B. These emitted signals can be detected by sensors **102** and/or **104** in lateral A.

In other examples, signal emitters in lateral A can be used to emit signals that are propagated through the formation between laterals A and B. The propagated signals can be detected by sensors in the logging tool **140**. The sensors of the logging tool **140** can be used to detect a property of the formation between laterals A and B, or to measure a characteristic in lateral B. Also the sensors of the logging tool **140** can be used to sample fluids (and perform chemical detection) at different locations in lateral B.

Assuming that the fluids in the formation between laterals A and B have a physical contrast (such as resistivity, conductance, and so forth), the front of fluids between the two laterals or surrounding the producing lateral can be inferred from measurements by the combination of the sensors in lateral A and sensors in the logging tool in lateral B.

In other examples, signals emitted by emitters of acoustic, electromagnetic, gamma radiation or other such physical emissions can be used for purposes of illuminating a subterranean formation below a casing point allow logging tools to detect physical transmission of such signals through the various layers of the formation. This concept can be used to assist in measurements ahead of a drill bit, such as a drill bit on a drill string provided in lateral B.

FIG. 1C shows another variant of the FIG. 1A arrangement. In FIG. 1C, the inductive coupler portions **128** and **130** of FIG. 1A are omitted. In examples according to FIG. 1C, an electrical cable **150** runs from the inductive coupler portion **124** to an uphole location (e.g. earth surface equipment or downhole controller). The electrical cable **150** can be run outside of the liner **101**.

In the various configurations described herein, electrical transceivers can be provided in the lateral branch equipment for emitting high energy electromagnetics and or microwave for purposes of triggering certain chemicals in cement or polymer or other suitable material to change state. For example, microwave energy can be used to set an epoxy seal behind casing, or break encapsulation in cement to activate setting.

Other devices that can be used include arrays of casing corrosion monitoring sensors, cathodic protection terminals behind a liner, and so forth.

Arrangement Type #2

FIGS. 2A-2C depict example well equipment according to arrangement type #2. Generally, the arrangement type #2 includes an injection lateral branch (lateral A) and a separate production lateral branch (lateral B) to allow for simultaneous fluid injection and production.

FIG. 2A illustrates an arrangement of well equipment that can be configured to allow for simultaneous production and injection from different lateral branches, while affording monitoring operations to detect fluid through a formation between the lateral branches. FIG. 2A illustrates the segmented control of injected fluids into lateral A with an open production lateral branch (lateral B) to allow introduction of logging tools. In FIG. 2A, lateral B is left open hole, allowing the intervention of various logging devices to detect fluid flow within the lateral branch or to emit or detect signals to or from the injection lateral sensors/transceivers. In other examples, lateral B can be lined with a liner.

The equipment in lateral A is similar to the equipment in lateral A of FIG. 1A, and thus share the same reference numerals. In the injection lateral branch (lateral A), injected fluids are controlled using electrically (or hydraulically) actuated flow control devices **106**, and isolation packers **114** and **116** cause injected fluids to be provided into predetermined locations within the injection lateral branch. This injection arrangement can be altered at any time during the life of the well by manipulation of one or more of the flow control devices. The sensors and/or transceivers placed in the injection lateral branch (lateral A) allow the sensing of the fluids in the injection lateral branch as well as sensing of fluid front movement between the two lateral branches.

In the main wellbore **125** of FIG. 2A, two tubing strings are provided, a "long" tubing string **202** and a "short" tubing string **204**. The long tubing string **202** and the short tubing string **204** extend through a dual packer **206** set in the main wellbore **125** against the liner **101**. The dual packer **206** has bores through which the long tubing string **202** and short tubing string **204** can extend. In addition, the dual packer **206** has a feedthrough path through which the electrical cable **134** can extend, as shown in FIG. 2A.

In some examples, the long tubing string **202** extends through the main wellbore **125** into lateral B. The short tubing string **204** extends through the dual packer **206** to a location in the main wellbore **125** just below the dual packer **206**. The long tubing string **202** can be used for fluid production, while the short tubing string **204** can be used for fluid injection. In different examples, the long tubing string **202** can be used for fluid injection, while the short tubing string **204** can be used for fluid production.

In other examples, instead of using the tubing strings **202** and **204** that are placed side-by-side to perform simultaneous injection and production, two concentric tubings can be used instead (with a second tubing concentrically arranged around a first tubing). An inner conduit of the first tubing can be used as an injection fluid path, while the annular region between the first and second tubings can be used as a production fluid path, or vice versa. As further examples, fluids can be pumped down the annulus between tubing **202** and liner **101**.

The short tubing string **204** has an opening that is downhole of the packer **206**, such that fluid injected through the short tubing string **204** is injected into an annular region around the long tubing string **202**. Fluid that is produced into lateral B flows into the inner conduit of the long tubing string **202**, as indicated by arrows **208**. The produced fluid can pass through the long tubing string **202** to an uphole location, such as the earth surface or some other uphole location.

As further shown in FIG. 2A, isolation packers **218** and **220** can be set between the long tubing string **202** and the wall of lateral B, to provide hydraulic isolation. By using the various sealing elements depicted in FIG. 2A, the injection fluid path and production fluid path are isolated from each other.

As with the FIG. 1A implementation, the liner **101** is mounted with the female inductive coupler portion **128**. A male inductive coupler portion **210** is mounted on the long tubing string **202**. The male inductive coupler portion **210** can have a flow-through passageway **212** through which injected fluid that flows from the short tubing string **204** can pass (as indicated by arrows **225**). The injected fluid passes through the flow-through passageway **212** of the male inductive coupler portion **210** and into the inner conduit of the tubing **110** that is in lateral A. The male inductive coupler portion **210** can be referred to as a flow-through male inductive coupler portion.

When the flow control devices **106** on the tubing **110** are opened, the injected fluids can pass through the flow control devices **106** into the adjacent formation, as indicated by arrows **214**. The injected fluids push fluids in the formation into lateral B as production fluids (as indicated by arrows **216**).

FIG. 2A also shows a logging tool **222** (which can be similar to the logging tool **140** in FIG. 1B) that is carried on a carrier line **224** (or by a tractor). The logging tool **222** in lateral B can cooperate with the equipment in lateral A to perform cross-well logging.

FIG. 2B shows another example arrangement that is similar to the arrangement of FIG. 2A, except that in FIG. 2B, the long tubing string **202** of FIG. 2A has been extended with another tubing string section **230** in lateral B. In FIG. 2B, the logging tool **222** of FIG. 2A is omitted. Instead, the tubing string section **230** is provided with various sensors **232** on the outside of the tubing section **230**, as well as formation contact sensors **234**. The sensors **232** and **234** are similar to the sensors **102** and **104** in lateral A discussed above in connection with FIG. 1A.

The sensors **232** and **234** are connected to an electrical cable **236**. The electrical cable **236** can pass through feed through paths in isolation packers **238** and **240** mounted to the tubing section **230** for isolating respective zones in lateral B. In addition, the cable **236** can extend through isolation packers **218** and **220**, and through the fluid passageway **212** of the inductive coupler portion **210** and through the dual packer **206** to an uphole location, such as the earth surface or some other uphole location.

The tubing string section **230** is also provided with flow control devices **235** (similar to flow control devices **106** in lateral A). In FIG. 2B, both laterals A and B are provided with segmented control for injection and/or production operations. The segmented control is achieved by use of the isolation packers depicted in FIG. 2B, as well as the multiple flow control devices (**235** and **106**) for flow control in the respective different zones defined by the isolation packers.

FIG. 2C shows another example arrangement that is a variant of the arrangement of FIG. 2B. The arrangement of FIG. 2C has another female inductive coupler portion **250** mounted on the liner **101**. In addition, a male inductive coupler portion **252** is positioned adjacent the female inductive coupler portion **250**. The male inductive coupler portion **252** has an annular flow passageway **254** through which injection fluids can pass. According to FIG. 2C, the electrical cable **236** from lateral B is connected to the female inductive coupler portion **252** (rather than to an uphole location as in FIG. 2B). The liner inductive coupler portion **250** is connected to the cable **126**, which is also connected to the liner inductive

coupler portion **128**. By adding the inductive coupler portions **250** and **252** in the arrangement of FIG. 2C, the dedicated cable **236** of FIG. 2B that extends to the earth surface can be omitted; instead, communications between the equipment in lateral B and an uphole location can employ the inductive couplers depicted in FIG. 2C.

FIG. 2C also uses a straddle tubing **260**, which interconnects a long tubing string **262** and the tubing string section **230**. The straddle tubing **260** is designed to hydraulically connect the long tubing string **262** with the tubing string section **230** in lateral B. A series of production seals, such as v-packings, bonded seals, or other similar seals, can provide hydraulic integrity in the connections between the straddle tubular **260** and the long production string **262** and the tubing string section **230**. The straddle tubing **260** can be configured to run and lock in a nipple profile using a carrier line or a tractor. Use of the straddle tubing **260** facilitates the installation of the production lateral tubing section **230** as the straddle tubing **260** decouples the tubing string section **230** from the long tubing string **262** when installing the tubing string section **230**. Once the tubing string section **230** has been installed, the straddle tubing **260** can be run and set in place.

Using the example arrangements depicted in FIGS. 2A-2C, which are according to arrangement type #2, various features can be provided. For example, the arrangement type #2 can allow for simultaneous injection and production of fluids in a multilateral well, such that a dedicated injection lateral branch and a dedicated production lateral branch are provided. The arrangement type #2 also allows for the installation of permanent monitoring devices such as sensors and/or transceivers in one or both of the lateral branches of the multilateral well. These monitoring devices (whether or not combined with logging tools) can perform cross-well logging between laterals branches.

Although FIGS. 2A-2C show lateral A as being the injection lateral branch and lateral B as being the production lateral branch, in other examples, lateral B can be the injection lateral branch while lateral A can be the injection lateral branch.

Arrangement Type #3

FIGS. 3A-3D depict example well equipment according to arrangement type #3. Generally, the arrangement type #3 includes a monitoring lateral branch, an injection lateral branch, and a production lateral branch. The monitoring lateral branch is used to perform monitoring of fluid flow in the formation between an injection lateral branch and a production lateral branch of a multilateral well. Such arrangement can be used for early injection pilots where the construction of many wells can be based upon the success of this pilot. This can be useful in remote or environmentally sensitive areas, in subsea applications, or in extended reach or offshore applications where the cost and or regulations or risks can be relatively high.

As shown in FIG. 3A, an arrangement that has an injection lateral branch (lateral C), a production lateral branch (lateral A), and a monitoring lateral branch (lateral B) allows for simultaneous production and injection of fluids in different lateral branches, while providing a dedicated monitoring lateral branch. The position of the monitoring lateral branch is arbitrary with respect to the injection and production lateral branches, but can be provided to allow relatively efficient monitoring of the fluid position within the formation between the injection and production lateral branches.

FIG. 3A shows an example in which the injection lateral branch (lateral C) includes an injection tubing string **302** that includes passive flow control devices (e.g. choke orifices,

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nozzles, channels). The passive flow control devices provided along the tubing string **302** allows for injection (or production) of fluids along the length of the tubing string **302**. In the context of fluid injection, the injection fluid (indicated by arrows **304** in the interior conduit of the tubing string **302**) passes through orifice chokes, nozzles, or channels in the passive flow control devices in a way in which the flow of fluids from inside the inner conduit of the tubing string **302** to outside the tubing string **302** (as indicated by arrows **306**) is determined based on the differential pressure between the inner conduit and the outside of the tubing string **302**. In other implementations, instead of using passive flow control devices, active flow control devices (controlled by electrical commands, pressure pulse commands, or RFID (radio frequency identification) tags pumped in with injected fluids, for example) can be used.

The tubing string **302** extends in lateral C to a location **308** closer to the junction with a main wellbore **310**. An isolation packer **312** is provided at the upper portion of the tubing string **302** to provide fluid isolation between lateral C and the main wellbore **310**. In addition, isolation packers **314**, **316**, and **318** are provided along the tubing string **302** to isolate respective zones (that are isolated from each other) in lateral C.

Injection fluid flows through the main wellbore **310** along an annular path indicated by arrow **304**. The annular path is provided outside the main wellbore tubing string **324**. The injection fluid passes through a flow passageway of a male inductive coupler portion **322** that is mounted to the main wellbore tubing string **324**. The male inductive coupler portion **322** is positioned adjacent a female inductive coupler portion **326** that is mounted to a liner **328**. An electrical cable **330** is connected to the male inductive coupler portion **322**, and the electrical cable **330** extends to an uphole location (e.g. earth surface or some other uphole location).

The lower end of the main wellbore tubing string **324** is engaged with a seal bore packer **332**. The seal bore packer **332** has an inner seal bore in which the lower end of the main wellbore tubing string **324** can be engaged to seal hydraulically.

In addition, a perforated tubing joint **334** is attached to the seal bore packer **332**. The perforated tubing joint **334** has perforations in the housing of the perforated tubing joint, where fluids (e.g. production fluids) are allowed to flow through these perforations into an inner conduit of the perforated tubing joint.

The perforated tubing joint **334** is connected to another tubing section **336**, which extends into the monitoring lateral branch (lateral B). An isolation packer **338** is set around the lateral B tubing section **338** to isolate lateral B from the main wellbore **310**. In addition, in FIG. 3A, a plug **340** is located inside the inner conduit of the tubing section **336**, to block fluid flow in the inner conduit of the tubing section **336**. The plug **340** is retrievable—retrieval of the plug **340** allows for fluid flow through the inner conduit of the tubing section **336**, as well as deployment of a tool through the tubing section **336**. The plug **340** can be hydraulically actuated by a control line run outside of tubing section **336** up to a hydraulic wet mate connection at **332**. The hydraulic wet mate connection at **332** can hydraulically connect to a hydraulic control line (not shown) run outside of tubing string **324** to the earth surface or other uphole location.

As explained further below, after the plug **340** is retrieved, a logging tool can be deployed through the tubing section **336** into lateral B for performing monitoring operations according to various implementations.

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The production lateral branch (lateral A) includes various equipment, including sensors **342** and **344**, which are similar to sensors **102** and **104** discussed above in connection with FIG. 1A. The sensors **342** and **344** are connected to an electrical cable **346**. Flow control devices **348** are also provided on a tubing **350**, inside lateral A. The upper end of the tubing **350** is connected to a whipstock **352**, which has a sealing element **354** set against the liner **328** to provide isolation between lateral A and the main wellbore **310**.

The electrical cable **346** is connected to a male inductive coupler portion **358** that is mounted on the tubing **350**. The male inductive coupler portion **358** is adjacent a female inductive coupler portion **360** mounted to the liner **328**.

The female inductive coupler portion **360** is connected to an electrical cable **362**, which extends outside the liner **328** to the female inductive coupler portion **326**.

In operation, injection fluid is flowed into lateral C (the injection lateral branch). The injection fluid flows into the adjacent formation around lateral C, which causes production fluid to flow into the production lateral branch (lateral A). The flow control devices **348** in the equipment provided in the production lateral branch (lateral A) can be selectively activated to control production flow through selected zones.

To allow for monitoring of fluid flow in the formation between the injection lateral branch and the production lateral branch, a logging tool can be provided into the monitoring lateral branch (lateral B) as depicted in FIG. 3B.

FIG. 3B shows the arrangement of FIG. 3A, except with the plug **340** in the tubing section **336** removed. In FIG. 3B, a logging tool **370** (carried on a carrier line **372** or by a tractor) has been deployed through the main wellbore tubing string **324** and through the tubing section **336** into lateral B. The logging tool **370** can perform cross-well logging operations, including monitoring fluid flow through the formation between laterals C and A.

FIG. 3C is similar to the arrangement of FIG. 3A, except that the monitoring lateral branch (lateral B) is provided between the production lateral branch (lateral A) and the injection lateral branch (lateral C). The equipment in the monitoring lateral branch (lateral B) is the same as the equipment used in the production lateral branch (lateral A) shown in FIG. 3A, and thus the components are assigned the same reference numerals.

The production lateral branch (lateral A) is provided with a tubing string **380**, which has respective sensors **382** and **384** (similar to sensors **102** and **104** in FIG. 1A), as well as flow control devices **387**. The sensors **382** and **384** and flow control devices **387** can be connected to a cable **385**, which can extend through the packers **386** and **390** to male inductive coupler portion **383** that is positioned adjacent female inductive coupler portion **385** that is mounted to the liner **328**. An electrical cable **391** connects the female inductive coupler portions **326** and **385**.

The isolation packers **390** provided on the tubing **380** define isolated zones. In addition, the isolation packer **386** is also provided at an upper portion of the tubing string **380** in the production lateral branch (lateral A) to isolate lateral A from the main wellbore **310**.

FIG. 3D illustrates a variant of the FIG. 3A arrangement. In FIG. 3D, instead of using the passive flow control devices in the injection tubing string **302** of FIG. 3A, active flow control devices **393** provided along the injection tubing string **388** are used instead. The actively controlled tubing string **388** can include various sensors **397** and **399** connected to an electrical cable **392**. In addition, the flow control devices **393** are connected to the electrical cable **392**, which extends through various isolation packers **394** and **395** to the inductive coupler

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portion 322. The flow control devices 393 can be selectively activated in response to commands over the cable 392.

Well/Lateral Design

The designs of lateral branches can depend on the type of treatment being monitored. One type of treatment is miscible gas injection, in which gas is mixed with other fluids. It may be desirable to use sensors in the various arrangements discussed above to detect gravity segregation of fluids (fluids are separated due to gravity). For example, a lateral branch in a multilateral well can be designed to extend vertically or at least have a vertical component above the injection points.

In another example, for injection of chemical agents that alter fluid mobility within a formation, an area-spaced lateral branch(es) (a lateral branch spaced from another lateral branch) may be beneficial to determine the viscous fingering propensity of the fluids injected. Injection of a less viscous fluid can displace a more viscous fluid in a formation, which can result in creation a pattern in a morphologically unstable interface between the two fluids in a porous medium.

In some examples, a lateral branch can be of a “corkscrew” type, which “winds” itself around a main injection bore. This can allow the placement of sensors (or logging tools) to have detection points above, below, and at radial spacing from the main injection bore.

In another example, a “meandering” lateral branch can be used, where the direction and position of this lateral branch are designed to focus monitoring (or emitting) devices on studying certain aspects of the intra-lateral region, such as a subterranean region exhibiting heterogeneity, a region having a cluster of fracture clusters, and so forth.

More generally, a path of a second lateral branch (with respect to a first lateral branch) can be defined to allow for acquisition of a desired image (of fluid movement) between the first and second lateral branches. The two (or more) lateral branches can be parallel, can be vertically or areally spaced apart, or can have a more complex relative arrangement (e.g. corkscrew or meandering as noted above).

Another application may involve targeting drilling of well paths that would benefit from a level of reservoir “illumination” while drilling. An example would be to initially drill a first lateral branch into, below or above a formation of interest. Once drilled, a liner can be set and certain electrically or hydraulically driven devices (e.g. signal emitter(s) and/or signal receiver(s)) can be placed therein. These devices can be designed to emit electromagnetic, acoustic or other signals into the formation surrounding the lateral branch. A second lateral branch can then be drilled with specific detection devices that utilize the emitted signals from the first lateral branch (and/or emitted signals from a main wellbore) to detect changes in the formation or fluids within that the well is targeted in penetrating. This can be repeated for multiple laterals. With such application, the following can be performed, for example: identification of rich organic content shales in a shale oil or gas play, identification of bypassed hydrocarbons, detection of certain formation types, identification of zones of high pressure contrast, safe drilling of wells (while avoiding collision) where wells are designed to be in close proximity, and so forth.

In the foregoing description, numerous details are set forth to provide an understanding of the subject disclosed herein. However, implementations may be practiced without some or all of these details. Other implementations may include modifications and variations from the details discussed above. It is intended that the appended claims cover such modifications and variations.

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What is claimed is:

1. A method comprising:

providing first equipment in a first lateral branch of a well; providing second equipment in a second lateral branch of the well;

performing cross-lateral logging using the first and second equipment in the corresponding first and second lateral branches;

injecting a fluid into one of the first lateral branch or the second lateral branch; and

using the cross lateral logging to monitor a front of fluid in a formation into which the first lateral branch and the second lateral branch extend.

2. The method of claim 1, wherein providing the first equipment comprises providing a signal emitter in the first lateral branch, and wherein providing the second equipment comprises providing a signal sensor in the second lateral branch.

3. The method of claim 2, wherein providing the first equipment comprises providing one of a permanent well equipment and a logging tool, and wherein providing the second equipment comprises providing one of a permanent well equipment and a logging tool.

4. The method of claim 1, wherein injecting comprises injecting fluid into the first lateral branch, wherein the second lateral branch is a monitoring branch; and further comprising monitoring the injecting of the fluid using the second equipment in the second lateral branch.

5. The method of claim 1, wherein injecting comprises injecting fluid into the first lateral branch; and as fluid is injected into the first lateral branch, producing fluid from the second lateral branch.

6. The method of claim 1, further comprising:

monitoring a subterranean structure adjacent the second lateral branch using a sensor in the second lateral branch.

7. The method of claim 1, wherein the first equipment includes a logging tool, and the second equipment includes an array of sensors or an array of transceivers,

wherein performing the cross-lateral logging comprises performing monitoring of a subterranean structure between the first and second lateral branches using the logging tool and the array of sensors or array of transceivers.

8. The method of claim 1, wherein the first lateral branch is an injection lateral branch into which fluids are injected, and the second lateral branch is a monitoring lateral branch, the method further comprising:

producing fluids from a third lateral branch of the well.

9. The method of claim 1, further comprising using one or more inductive couplers to provide electrical communication with one or both of the first equipment and second equipment.

10. The method of claim 9, further comprising using hydraulic couplers to provide hydraulic communication with one or both of the first equipment and second equipment.

11. The method of claim 9, further comprising using optical couplers to provide optical communication with one or both of the first equipment and second equipment.

12. The method of claim 1, further comprising:

providing one or more flow control devices in one or both of the first and second lateral branches to control fluid flow.

13. The method of claim 1, further comprising guiding drilling of the second lateral branch based on deployment of one of a signal emitter or a signal receiver in the first lateral branch or in a main wellbore.

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14. The method of claim **1**, further comprising defining a path of the second lateral branch to allow for acquisition of an image between the first and second lateral branches.

15. A system for use in a multilateral well having lateral branches, comprising:

first equipment for deployment in a first of the lateral branches; and

second equipment for deployment in a second of the lateral branches,

wherein the first and second equipment are arranged to cooperate to perform cross-lateral logging, at least one of the first and second equipment further comprising a flow control device actuatable based on data from the cross lateral logging to affect a fluid front between the first and second laterals.

16. The system of claim **15**, wherein the second equipment includes a sensor to detect signals in a formation adjacent the second lateral branch.

17. The system of claim **16**, further comprising an electrical cable and an inductive coupler, the sensor connected to the

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electrical cable, and the inductive coupler to enable communication between the sensor and an uphole component.

18. The system of claim **16**, wherein the second equipment further includes the flow control device that is selectively activatable to block or allow fluid flow.

19. The system of claim **16**, wherein the first equipment includes a logging tool for deployment into the first lateral branch, where the logging tool has a signal emitter, and the sensor is to detect a signal transmitted by the signal emitter as affected by the formation between the first and second lateral branches.

20. The system of claim **15**, further comprising third equipment for deployment in a third of the lateral branches, wherein the first lateral branch is for injection of fluids, and the third lateral branch is for production of fluids.

21. The system of claim **15**, wherein the first equipment includes flow control devices.

22. The system of claim **21**, wherein the flow control devices are selected from the group consisting of active flow control devices and passive flow control devices.

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